

Improved Ocean Environment Representation In Warfighting Simulations

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LONG-TERM GOALS

Provide full water column environment information in the most appropriate fashion for use in Synthetic Theater of War (STOW)/ Joint Countermine Operational Simulation (JCOS) for on-board training, Battle Force Tactical Training (BFTT)

OBJECTIVES

Determine the interactions and system requirements of the BFTT program. Establish and obtain ocean, wave, and acoustic models that would be appropriate for incorporation into the STOW/JCOS system. Perform tests to ascertain the sensitivity of the acoustic models to various water column parameters as well as the spatial and temporal resolution of the models. Provide the models for an initial test case for coastal water offshore of Camp Lejeune, North Carolina.

APPROACH

Ocean Models: For this work, we use a version of the Princeton Ocean Model (POM), ECOM (Estuarine Coastal Ocean Model). In ECOM, differential equations are used to account for local variations of a parameter, changes due to non-linear advection and turbulent diffusion, pressure effects due to the three-dimensional differences of density (i.e., salinity and temperature), and the temporal and spatial changes in the free surface height (tides, wind-induced setup or setdown, etc.) (Blumberg and Mellor, 1987). ECOM accounts for many sources and sinks in the equations of motion. These include time-varying river inflows, rainfall, and heat fluxes through sea-air interface.

The ECOM model has also been adapted to include the major wave effects (Lewis, 1998). By providing wave model results (wavelength, wave amplitude, wave period, and direction of propagation), ECOM can account for wave-enhanced bottom friction, currents induced by wave breaking, and currents resulting from the fact that wave motion is not entirely circular (referred to as

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Stokes drift). In addition, formulations exist for including the impact of waves resulting in a non-zero mixing length at the ocean surface.

Acoustic Models: From the salinity and temperature fields, we can calculate the three-dimensional structure of sound speed. With this information, we can utilize acoustic propagation models to ascertain detection levels within the water column for different ship-board systems. The acoustic models must use information from both the wave and circulation models to provide realistic predictions of transmission loss throughout the water column. In addition, bottom characteristics must be considered in order to account for reflection/absorption/roughness at the ocean bottom.

Our objective is to compute the three-dimensional acoustic field given the three-dimensional input data. Unlike the ocean models, there are a few true three-dimensional acoustic models. These are based on finite difference solutions to the wave equation and a three-dimensional solution using the parabolic equation (PE) approach. The PE models are very efficient in computing the field in a range dependent environment. None of these methods has been bench-marked, and their accuracy's are not known. The common practice is to treat the problem as a Nx2D (N x two-dimensional) model in which the acoustic field is calculated along N radial lines emanating from the source.

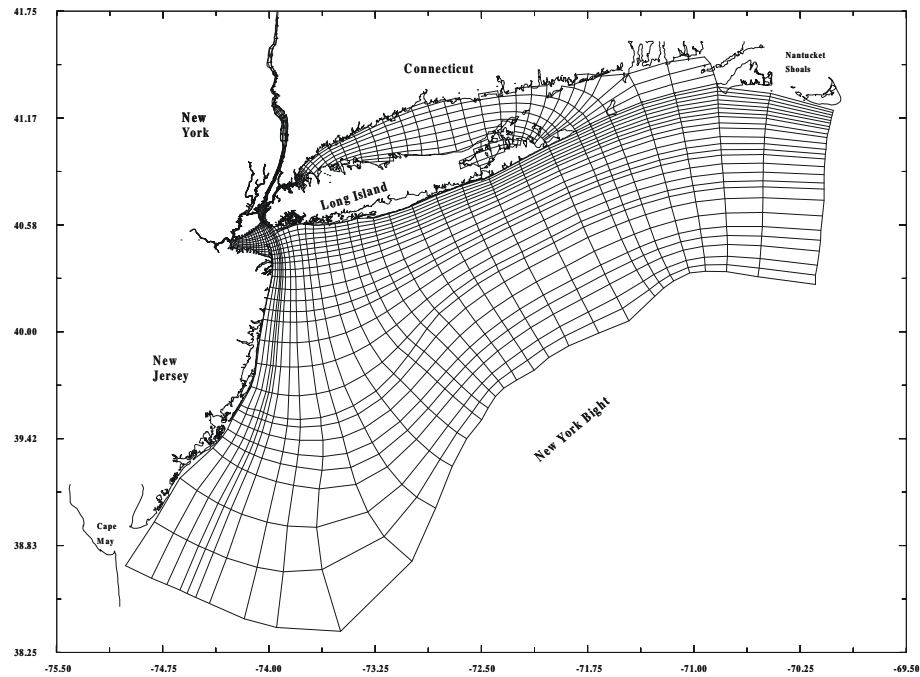
Coupling with Acoustic Models: Coupling with acoustic models is one-way, with ocean information feeding into the acoustic models. The acoustic models require the three-dimensional sound speed structure, and this is determined from the three-dimensional structure of the water column salinity and temperature as well as the depth of the water column. At any instance when the system requires transmission loss characteristics throughout the water column, the snap-shot of the three-dimensional sound speeds at that time is utilized.

Archive of the Results: Once models are coupled and ocean simulations are being conducted, the results must be archived for eventual use in the BFTT system. The question arises as to what spatial and temporal resolutions the model results must be archived in order to provide realistic variations of ocean environment for on-board training. We must consider data archiving factors related to changes in salinity, temperature, sound speed, etc., as a result of tidal variations, the passage of atmospheric fronts, or changes of freshwater inflows. And we must have some indication of the spatial extent of such changes. For realistic training scenarios, we wish to archive model predictions often enough in time and space to catch the more significant oceanographic variations that impact operations but not so often that data storage and retrieval problems result.

WORK COMPLETED

To get an indication of spatial and temporal scales, we utilized an existing, calibrated, and verified ocean model of the New York Bight region (Figure 1). This model has been developed in great detail over the last five years (Blumberg et al., 1999) and has relatively high resolution both in space and time. As such, the model predictions can provide realistic water column data both in deeper and shallower water. Time histories of model results (sea surface height, temperature, salinities, sound speed, and current velocity) were correlated with the time histories of adjacent model grid cells. As we move further away from a given grid cell, the correlations tend to drop, and we use the correlations as a function of distance to determine at what distance the correlation drops to e^{-1} (i.e., the e-folding space

scale). This allows us to quantify the distance at which we can expect the variations of an oceanographic variable to change significantly.



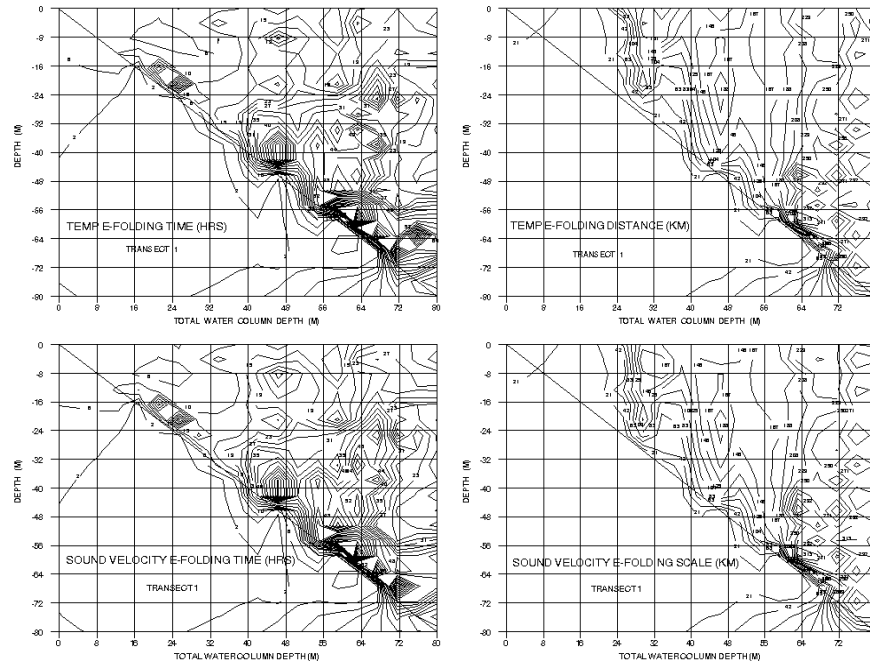
1. System Wide Eutrophication Model Grid

Along similar lines, we correlated the time histories of model results at a given grid cell with itself but lagged in time. With a greater time lag, the correlations become less, and we use these correlations as a function of time lag to determine the time when the correlation drops to e^{-1} (i.e., the e-folding time scale). The e-folding time scale quantifies the time span during which the variations of an oceanographic variable at a given location can be expected to change significantly.

Sound speed is strongly dependent on water temperature, with salinity and depth having only secondary effects. As such, we present the results of the e-folding scales for water temperature and sound speed for typical summer and winter conditions in the New York Bight. During summer, the surface waters can become substantially warmer than underlying water. In winter, the waters of the New York Bight are relatively well mixed and colder.

RESULTS

The result of the summer e-folding scales for an east-west offshore transect in the New York Bight are shown in Figure 2. E-folding calculations were also performed for an east-west transect that is in mostly shallower water running along the southern shore of Long Island. A third transect begins in deeper water, runs northward to the east end of Long Island, then westward into and through Long Island Sound. We can use the rule-of-thumb that, to resolve variations over these scales, we must store results at time steps or spatial scales that are one-fifth to one-tenth of the e-folding scale. Thus, an e-folding time of 20 hours at a given location translates to saving model results every 2-4 hours.

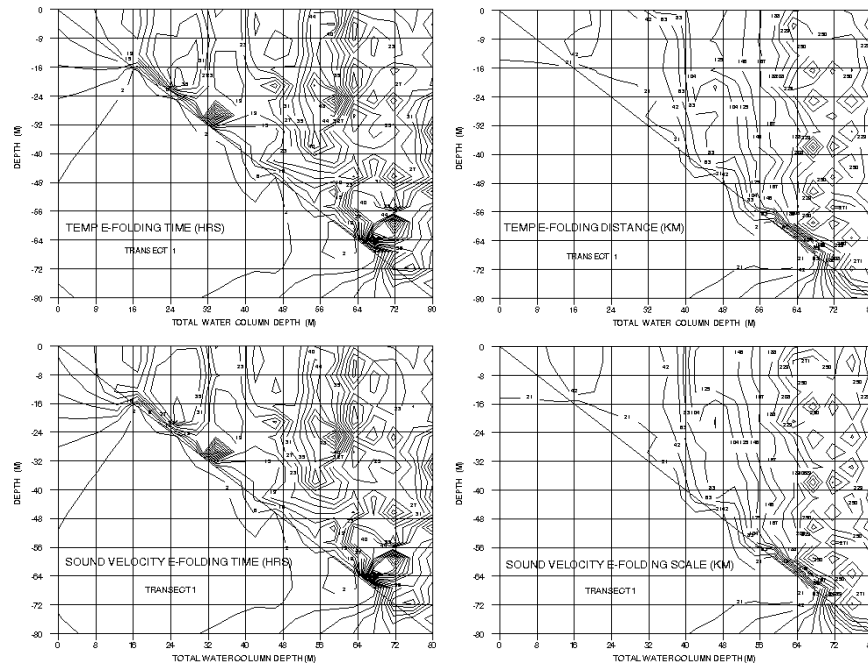


1. Examples of the summer-time e-folding time and space scales for water temperature and sound speed as calculated using results from the New York Bight ocean model. The diagonal line represents the ocean bottom, and contours below this line are an artifact of the contouring software.

In general using summer-time conditions for temperature, salinity, and sound speed, smaller scales are found in shallower water, with a number of exceptions to this generality. In water shallower than ~30 m and in the top 6 m of deeper water, model results should be archived about every 0.5 hours. Saving model results in deeper waters can be about every 2 hours. To be reliable in all regions, the spatial scale for archiving model results in water shallower than ~20 m should be ~400 m. In water depths of ~80 m, the spatial scale can be expanded to ~25 km in the longshore direction but only ~2 km in the cross-shelf direction.

The results of the e-folding calculations for the winter period are shown in Figure 3. There are some significant differences with respect to the summer results. For the length scale, if model results are archived at ~2 km resolution, we should be able to provide reasonable spatial variations of parameters. Results indicate that we could archive model results in water of ~80 m depth at a 20 km resolution in the longshore direction and ~2 km in the cross-shelf direction. So the archive scales are about 5 times greater in winter than those in summer.

As for time scales for the winter period, the indicated archive times from results from several transects are 1.5 to 2 hours. But the results from a shallow transect running along the shoreline just off Long Island indicate fairly small archive times with intervals as small as 12 minutes. There are also some implied archiving time scales of the order 15 minutes for the summer period, but they are not as extensive as the small time scales in winter for the same shoreline transect.



2. Examples of the winter-time e-folding time and space scales for water temperature and sound speed as calculated using results from the New York Bight ocean model. The diagonal line represents the ocean bottom, and contours below this line are an artifact of the contouring software.

IMPACT/APPLICATIONS

Although ocean and acoustic models can provide accurate predictions, the models can only respond to the forcings provided them, and we certainly do not have the capability to provide all the ranges of forcing with their spatial and temporal variabilities. This is particularly true for littoral regions where these variations are much greater than those in deep water. Thus, we would like to be able to quantify just how accurate the models are in the BFTT system. This can be done by modeling a particular region and by comparing the model results against observations. Since acoustic propagation plays such an important role in the warfighting scenarios, any region we would want to model would have to be one in which we could perform acoustic simulations. Such a region is the acoustic range off the coast of Camp Lejeune, where the U.S. Navy routinely conduct submarine exercises. This area provides an ideal site for quantifying the accuracies of ocean and acoustic models in the BFTT.

TRANSITIONS

None to date

RELATED PROJECTS

Maritime Virtual Environment Data Specification (MARVEDS): Dr. Sue Numrich and William Smith of Naval Research Laboratory

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